Deriving roof albedo for California cities using remote sensing

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References:

Ban-Weiss GA, Woods J, Levinson R, 2015. Using remote sensing to quantify albedo of roofs in California's seven largest cities, Part 1: Methods. *Solar Energy*, 115, 777-790.

Ban-Weiss GA, Woods J, Millstein D, Levinson R, 2015. Using remote sensing to quantify albedo of roofs in California's seven largest cities, Part 2: Results and application to climate modeling. *Solar Energy*, 115, 791-805.

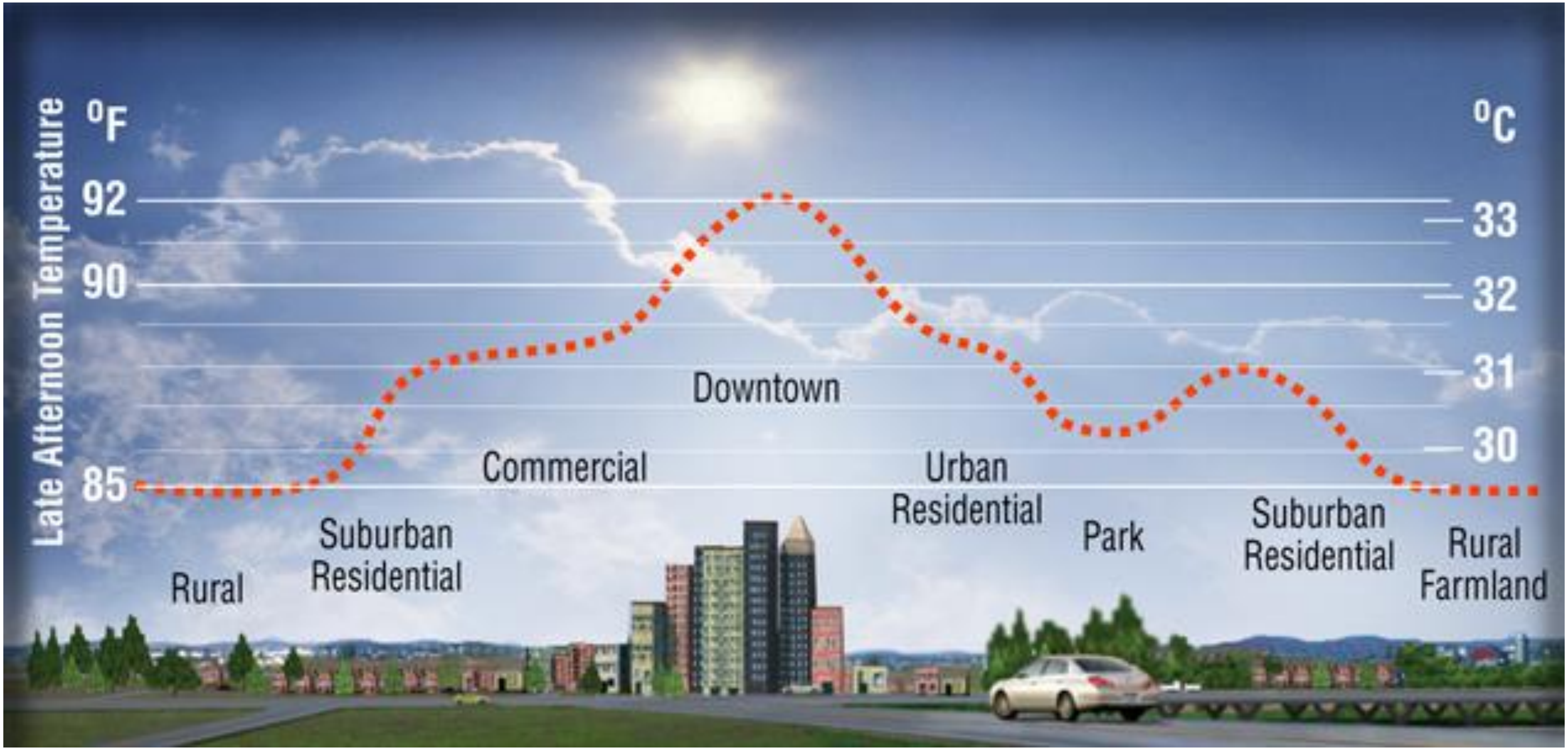
Sponsor: California Air Resources Board

California Environmental Protection Agency
AIR RESOURCES BOARD

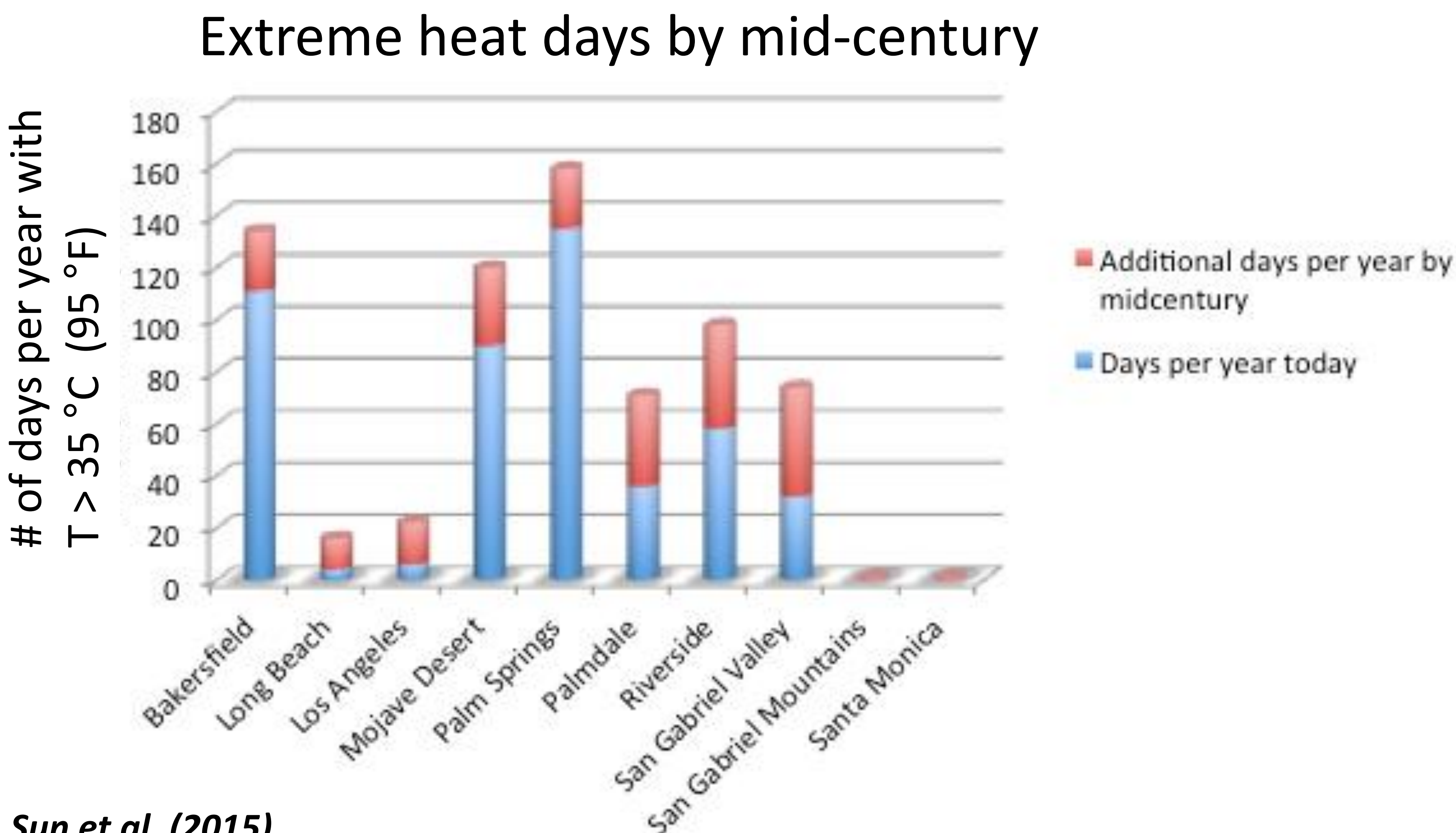
Motivation

- Buildings are responsible for ~40% of total energy use in U.S. (EIA, 2013)
- Many cities are "urban heat islands" with higher temperatures than surrounding areas
- Global climate change is projected to warm cities
- 81% of people in the U.S. live in cities as of 2010 (U.S. Census Bureau)
  - Worldwide rate is ~50%

The summer afternoon urban heat island effect



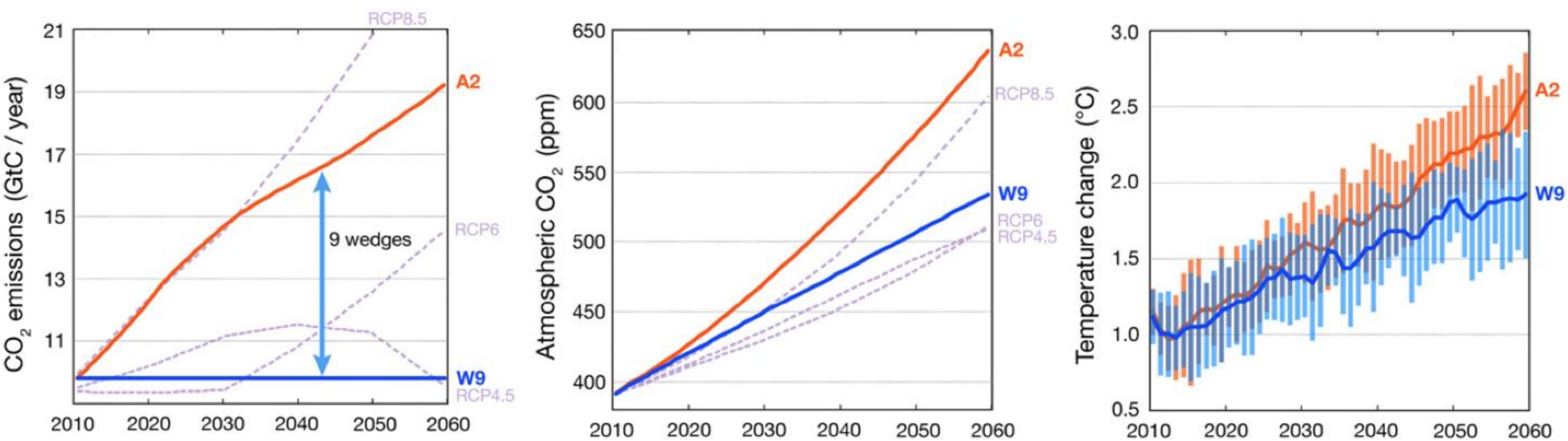
California cities are projected to warm over the next century



Sun et al. (2015)

On the need for local solutions for dealing with climate change

- Mitigating global climate change requires vast decreases in CO_2 emissions worldwide (top priority!)
- Given the lack of progress thus far, cities need local solutions to deal with local impacts of climate change



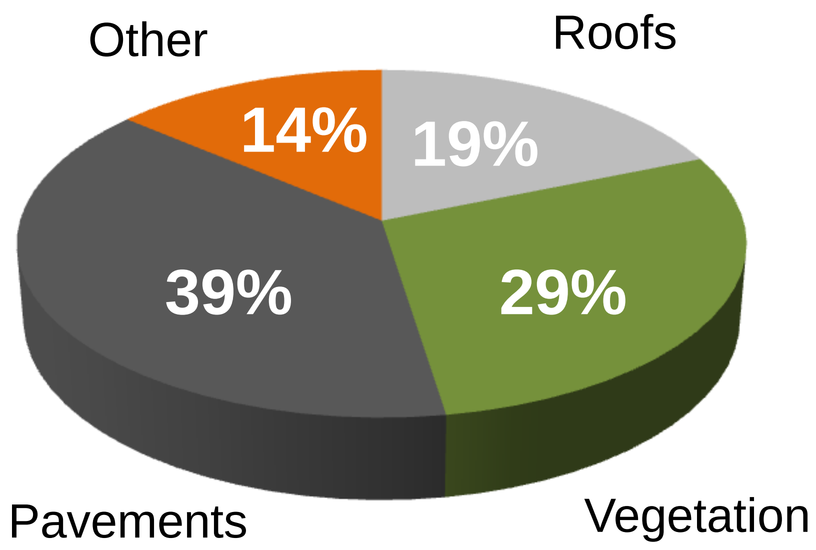
Davis et al. (2013) ERL

Methods to reduce urban heat

Reverse the local climate consequences of:

1) **Dark surfaces**
2) **Lack of vegetation**
3) **Anthropogenic heating**
4) **Thermally massive materials**

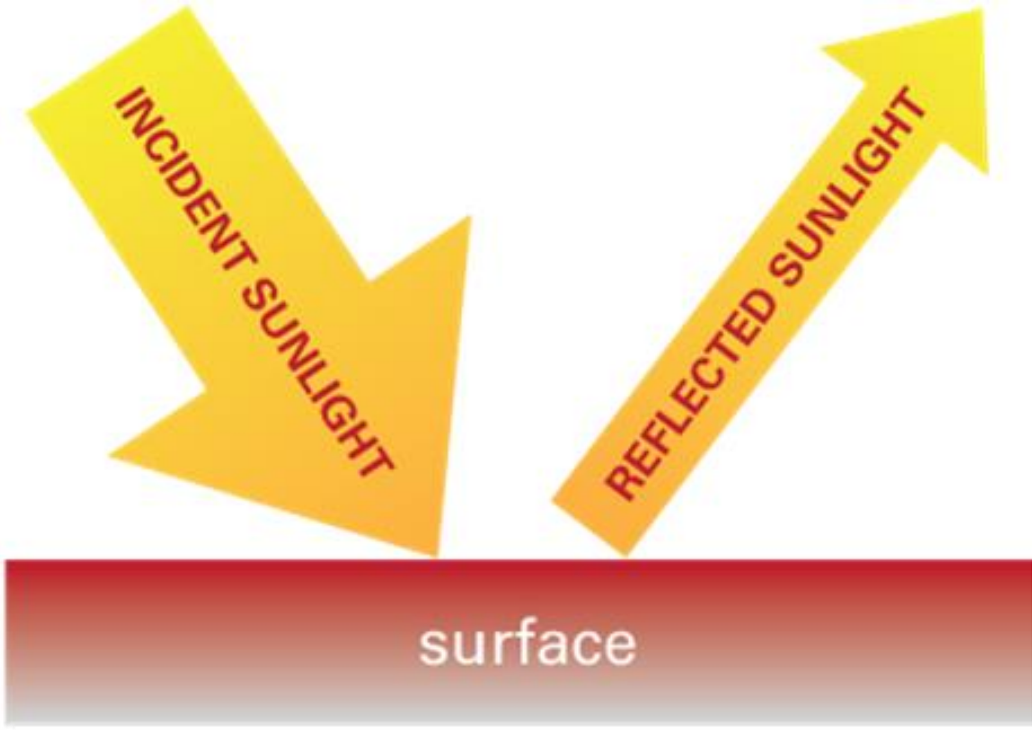
Fabric of a typical city



Some “cool community” strategies

- Cool roofs
- Cool pavements
- Vegetative roofs
- Street level vegetation

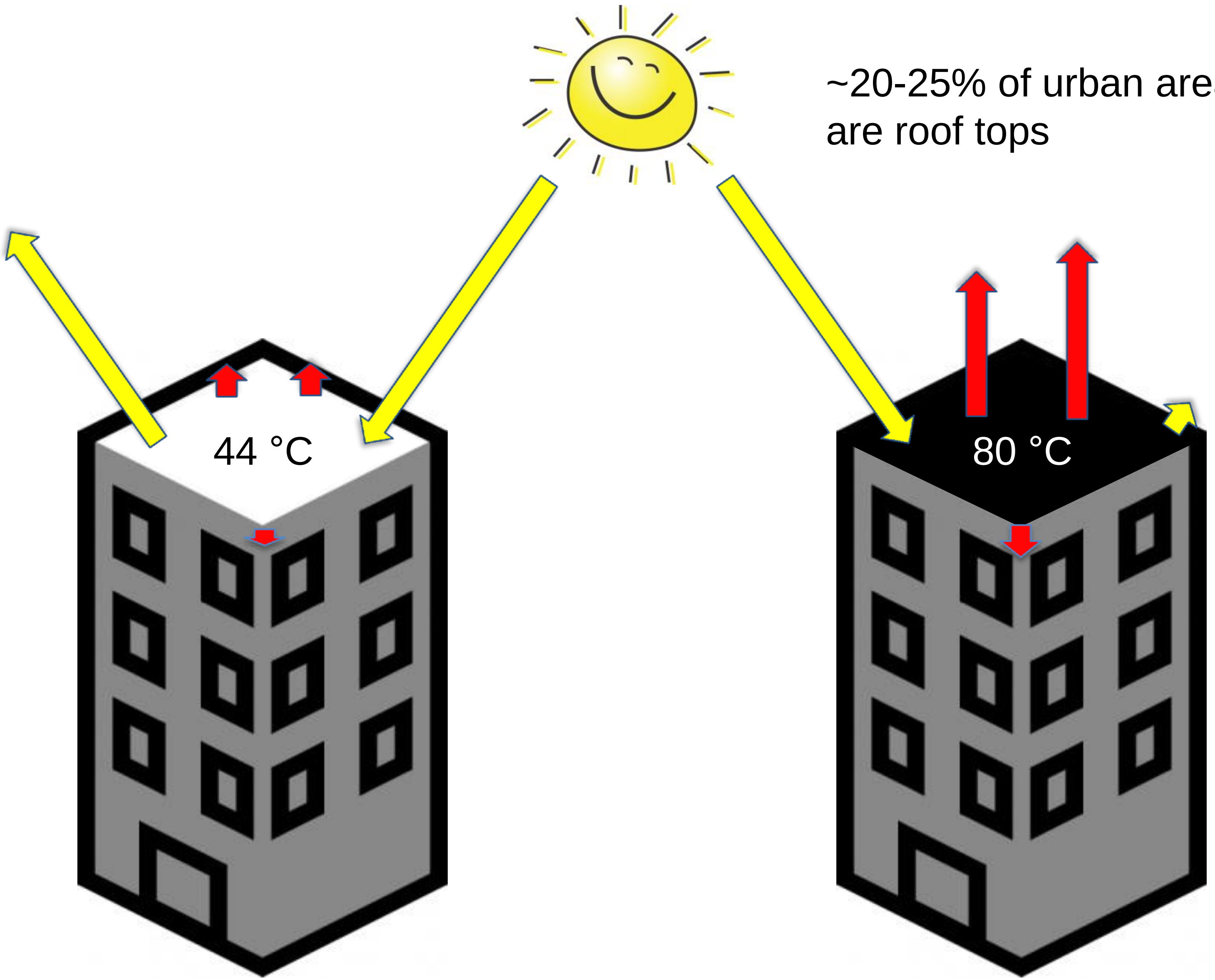
Solar reflectance (a.k.a. albedo)



Definition: The ratio of reflected to incident sunlight

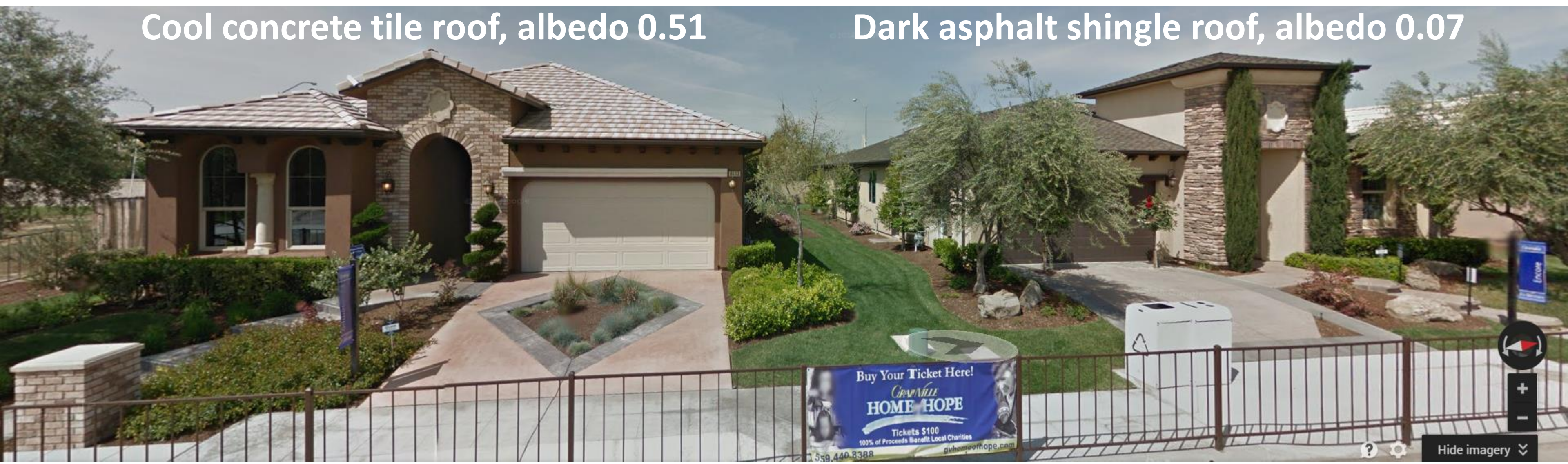
Solar reflective roofs can reduce building energy use AND lower urban temperatures

~20-25% of urban areas are roof tops



Cool roofs reduce energy use in most climates

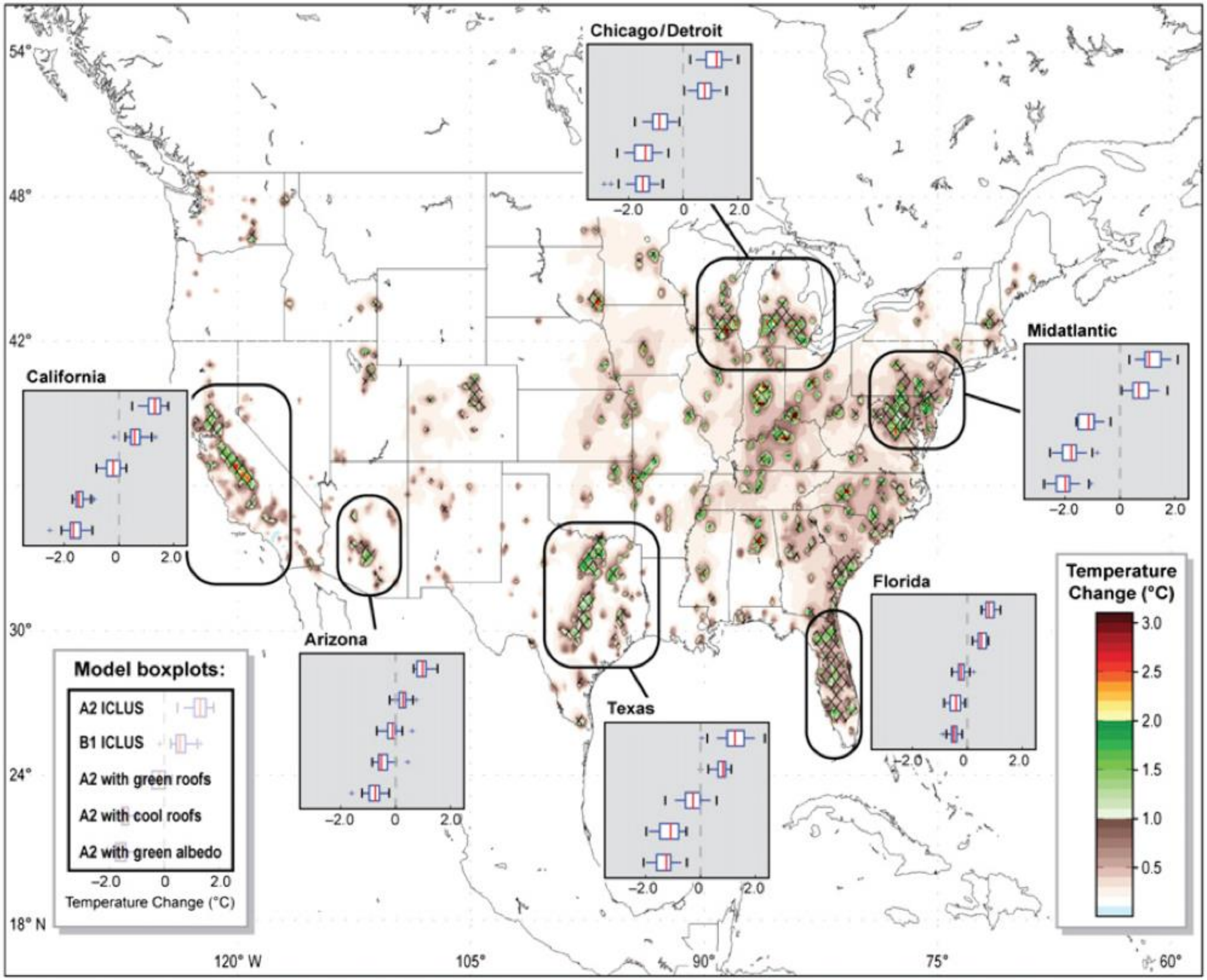
- Cool roofs can reduce cooling energy use by 10-20% or more



Roof footprint: 188 m^2 (2020 ft^2)
Annual HVAC energy cost savings: US$167 (20%)

Rosado et al. (2014)

Cool roofs can reduce urban temperatures



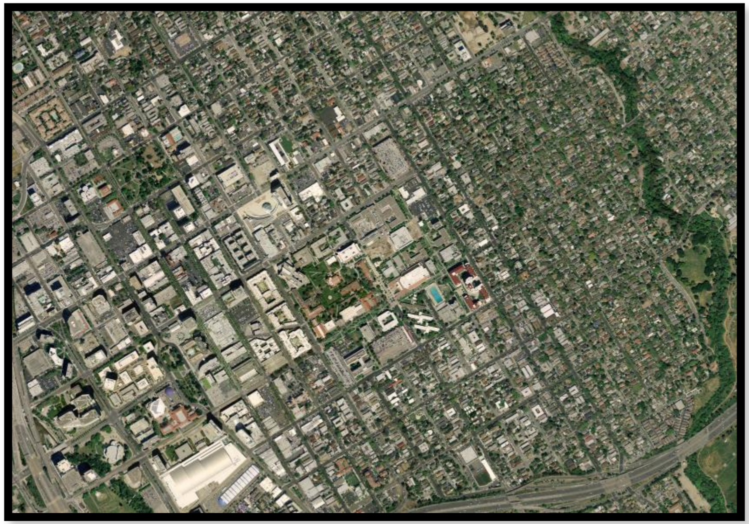
Georgescu et al. (2014)

Primary research question

Q: What is the maximum increase in roof albedo attainable in cities?

To answer, need to characterize current stock of roofs at city scale.

Possible data sources



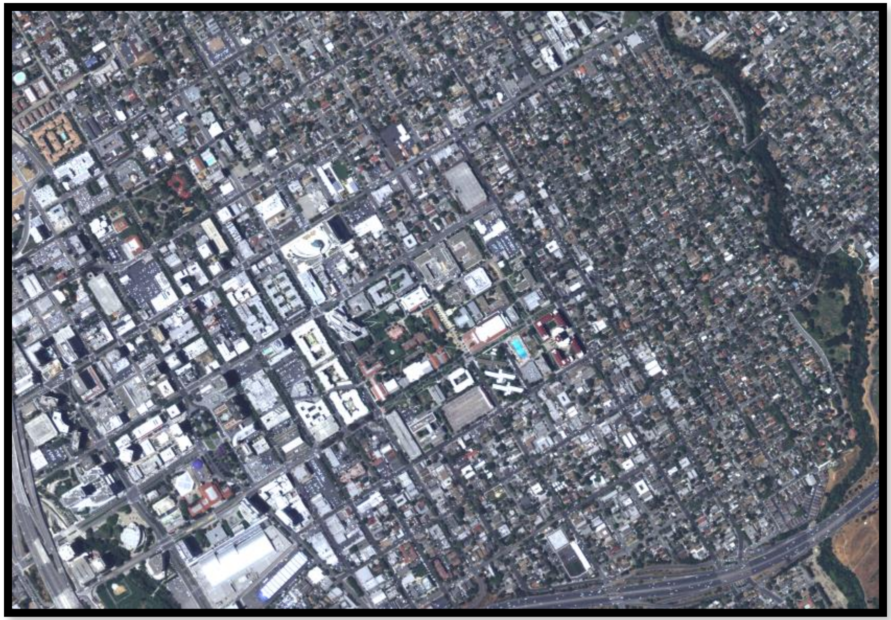
<u>Satellite</u>

1) NASA products (free)
   – Spatial resolution too low
2) Commercial satellites
   – Too expensive for our large areas of analysis

<u>Orthoimagery (acquired via airplane)</u>

– Not radiometrically calibrated
– Usually no near-infrared information

Possible data sources



National Agricultural Imagery Program (NAIP)

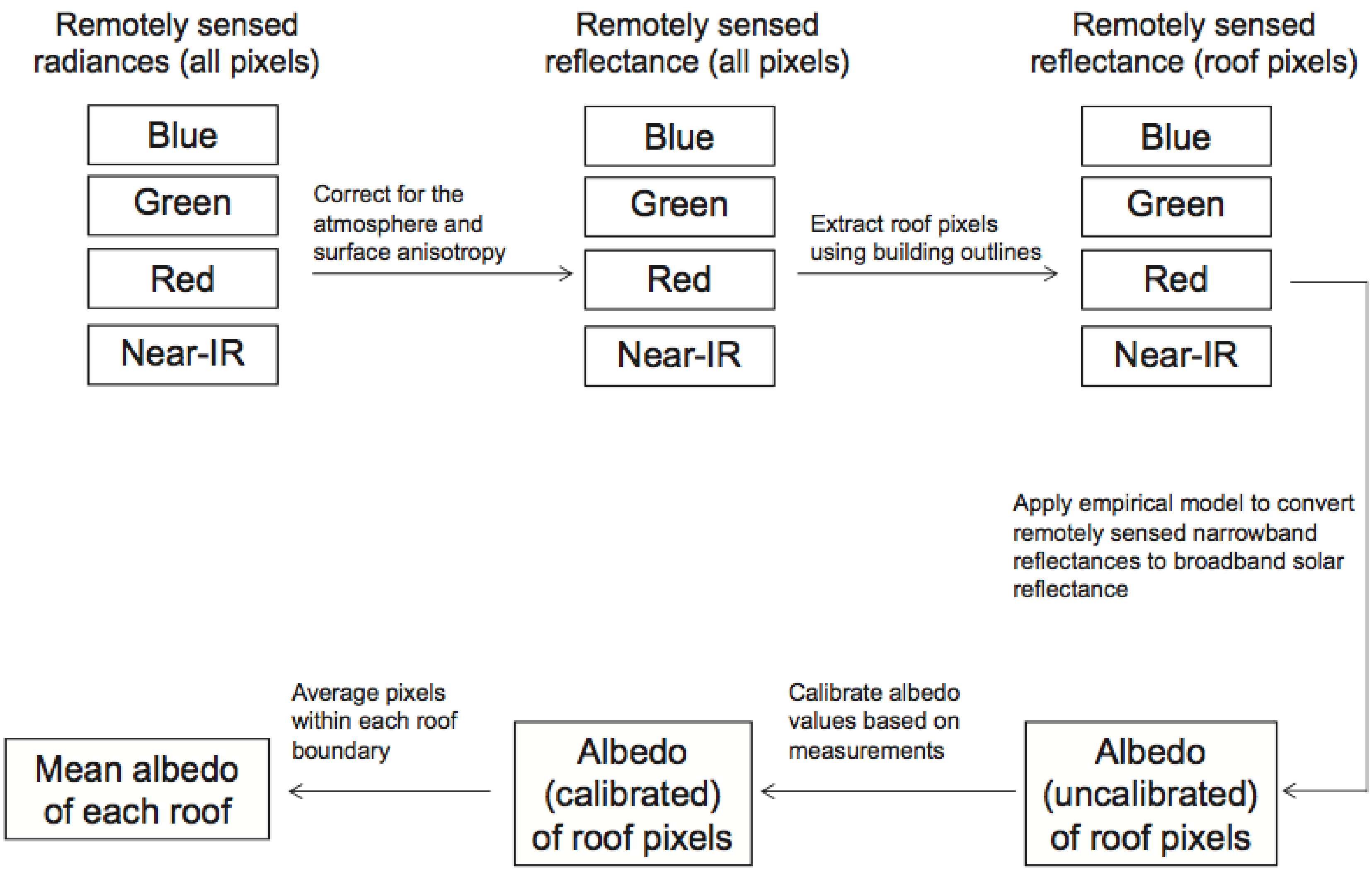
- Aerial imagery for all of California
- 1 meter spatial resolution
- 4 spectral bands
  - red, green, blue, near-IR
- Available for free via USGS
- BUT, not radiometrically calibrated

2009 was a special year …

- Northwest Group used a radiometrically calibrated sensor similar to those used on satellites
- Obtained raw sensor data and reprocessed

Spatial coverage of acquired data

Overview of our approach



Source: Ban-Weiss et al. (2015a)

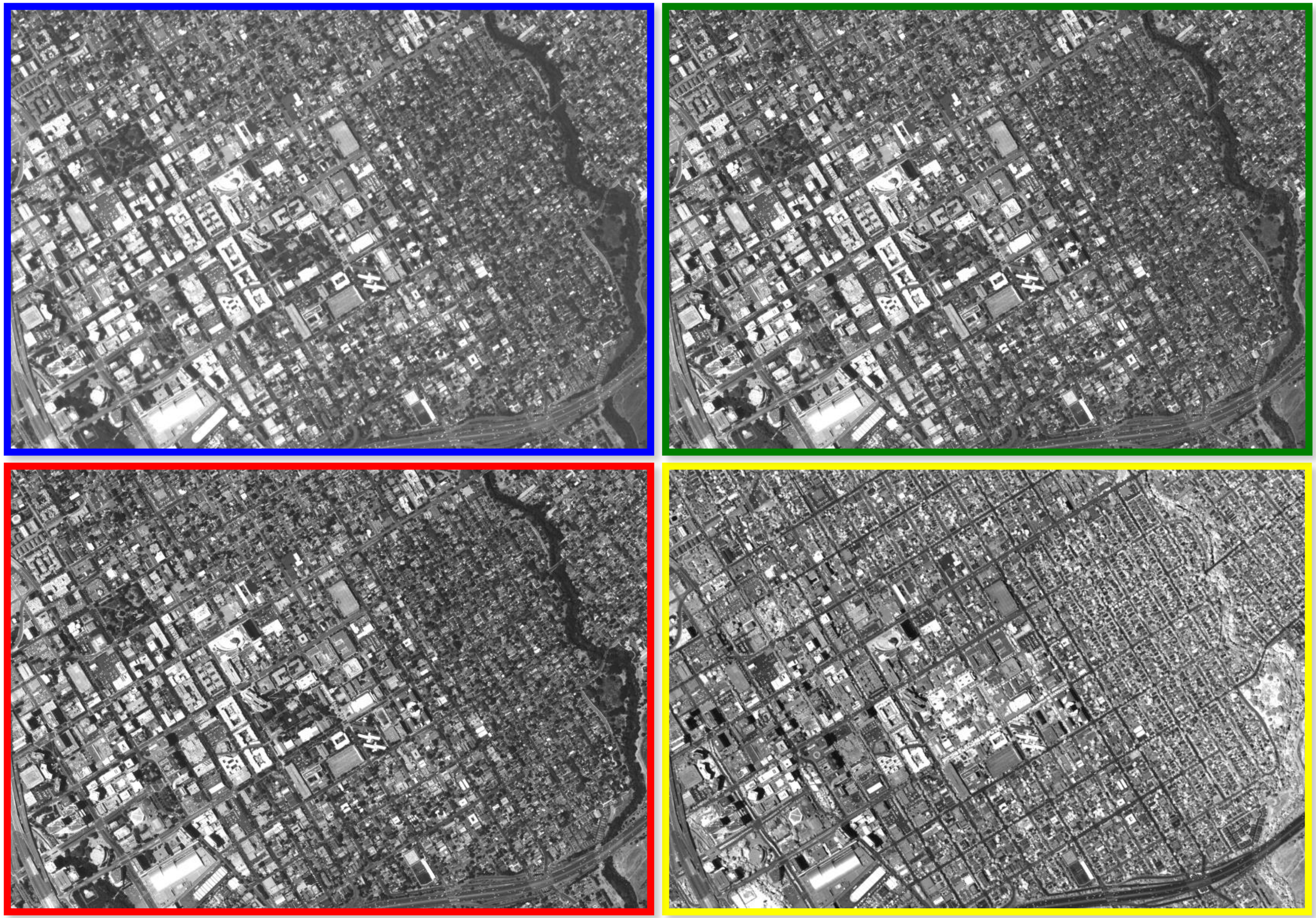
Example sensor data for each band

Band 1- Blue

Band 2- Green

Band 3- Red

Band 4- Near IR

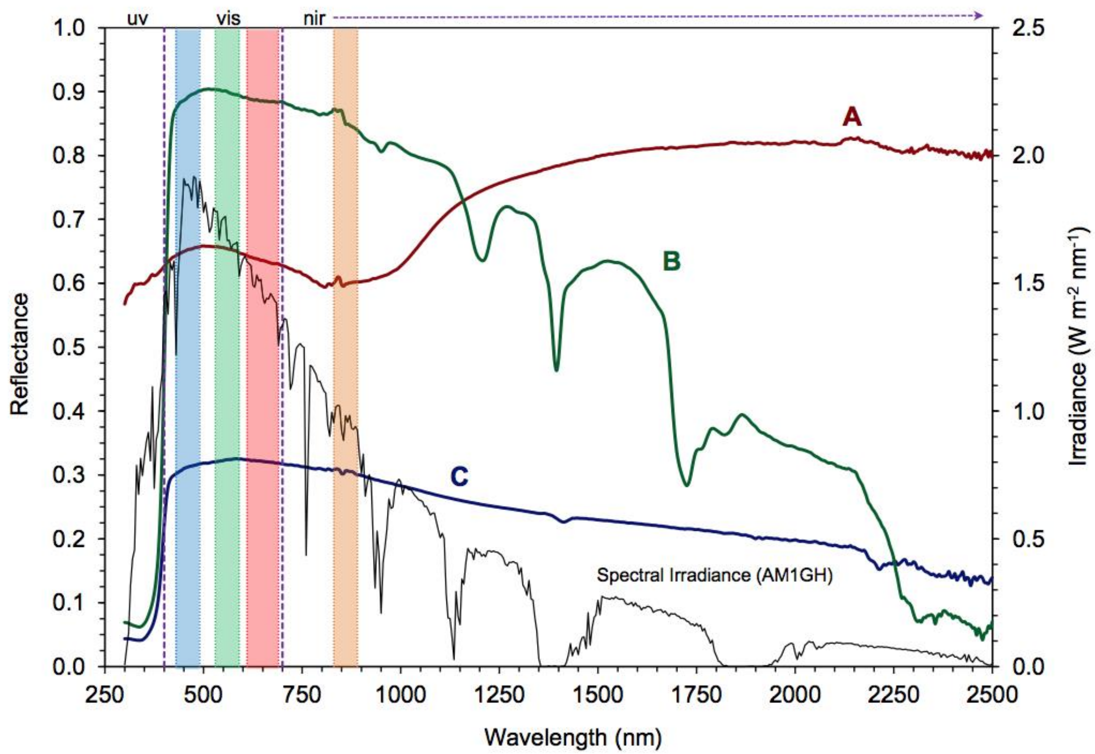


Source: Ban-Weiss et al. (2015a)

Extracting roof pixels using building outlines

Source: Ban-Weiss et al. (2015a)

Developing an empirical model to predict albedo from remotely sensed reflectances



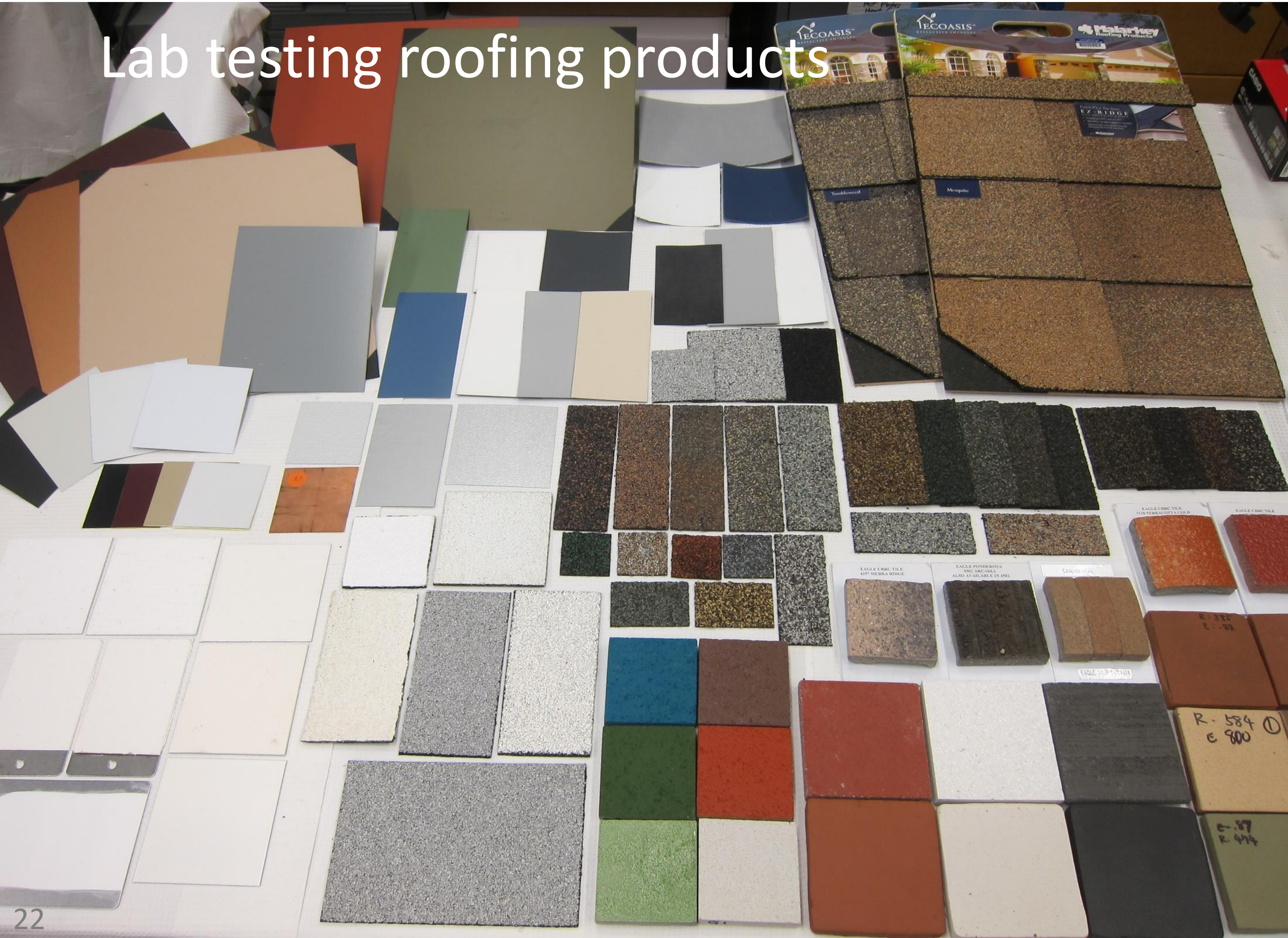
(A) Metal roof

(B) White membrane

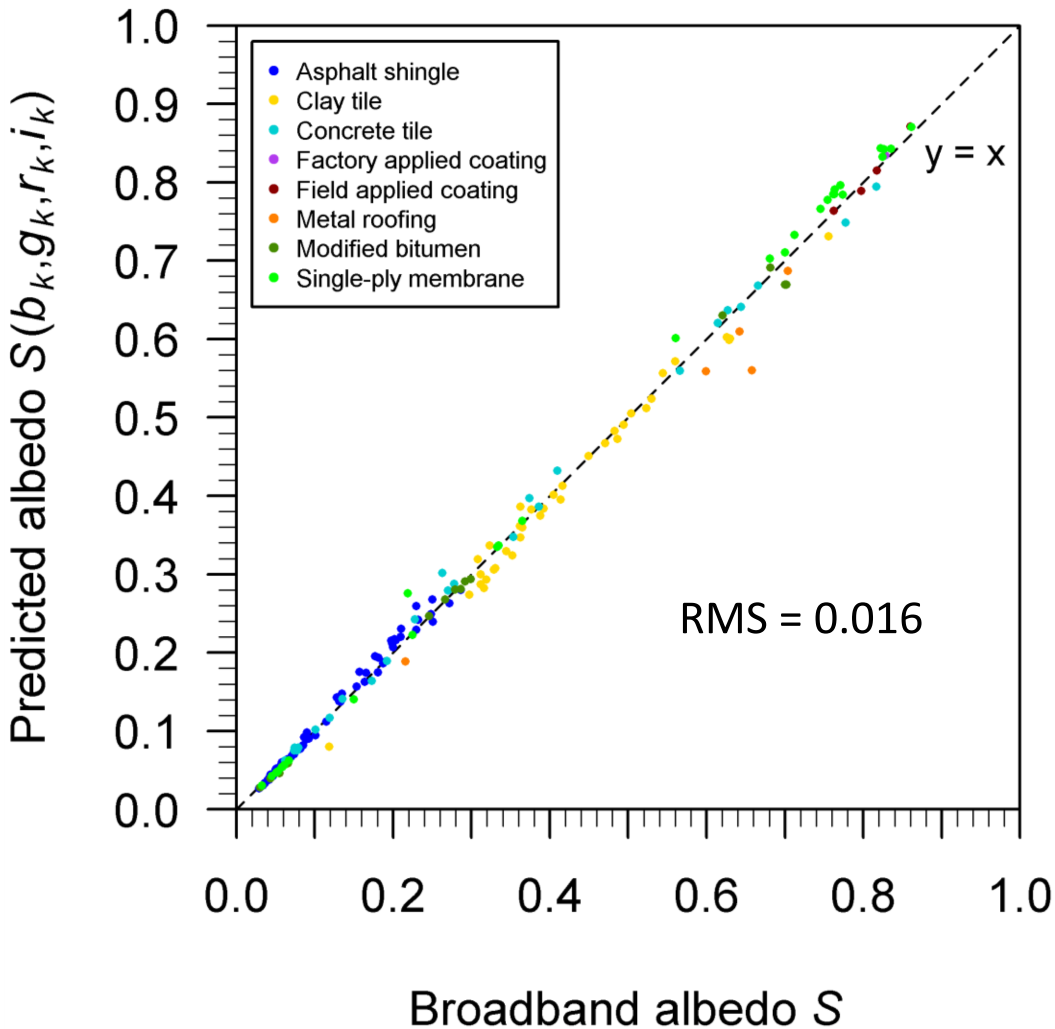
(C) Cap sheet

Source: Ban-Weiss et al. (2015a)

Lab testing roofing products



Predicting albedo from remotely sensed reflectances

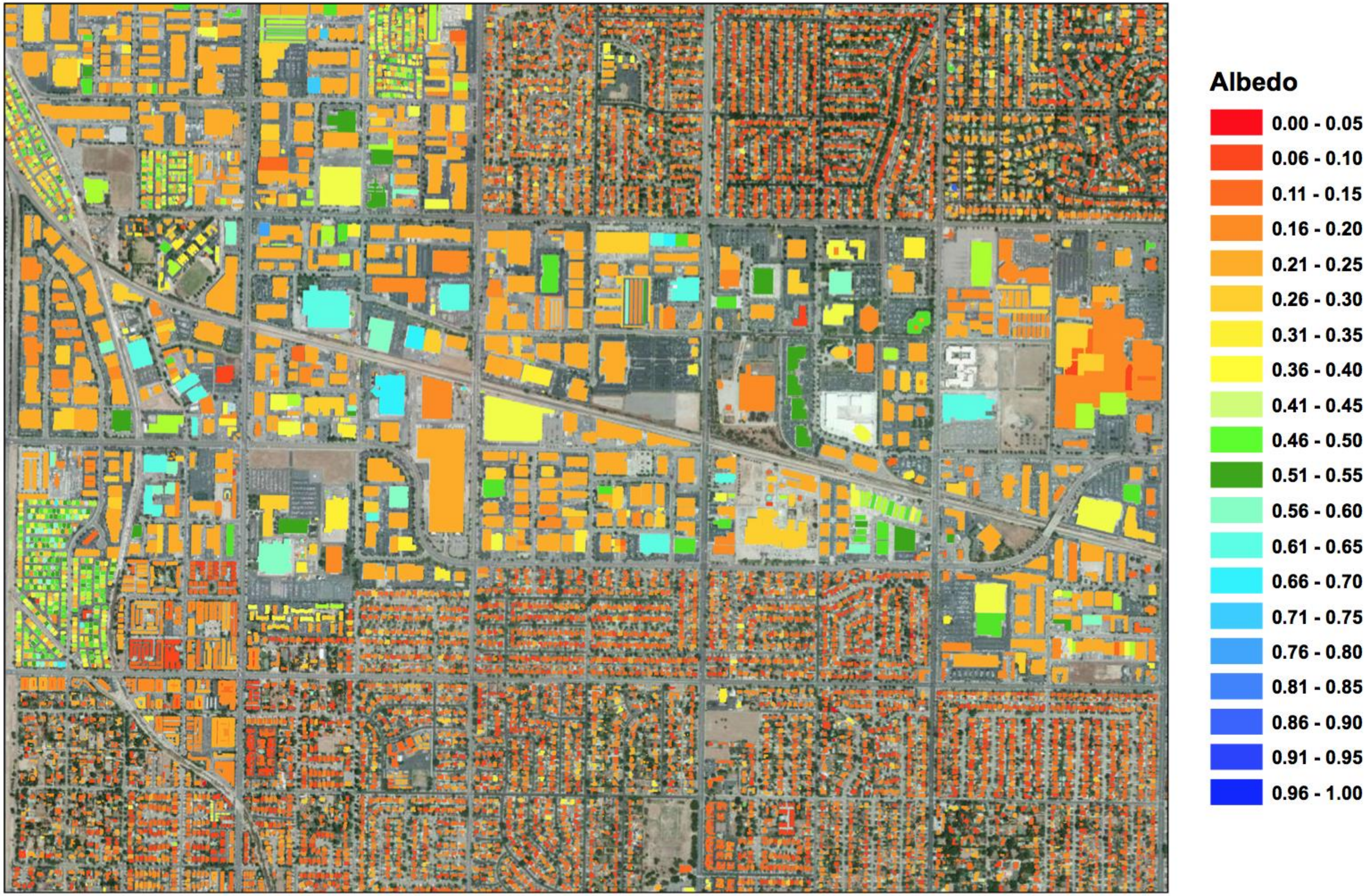


Source: Ban-Weiss et al. (2015a)

Ground-truthing remotely sensed roof albedo

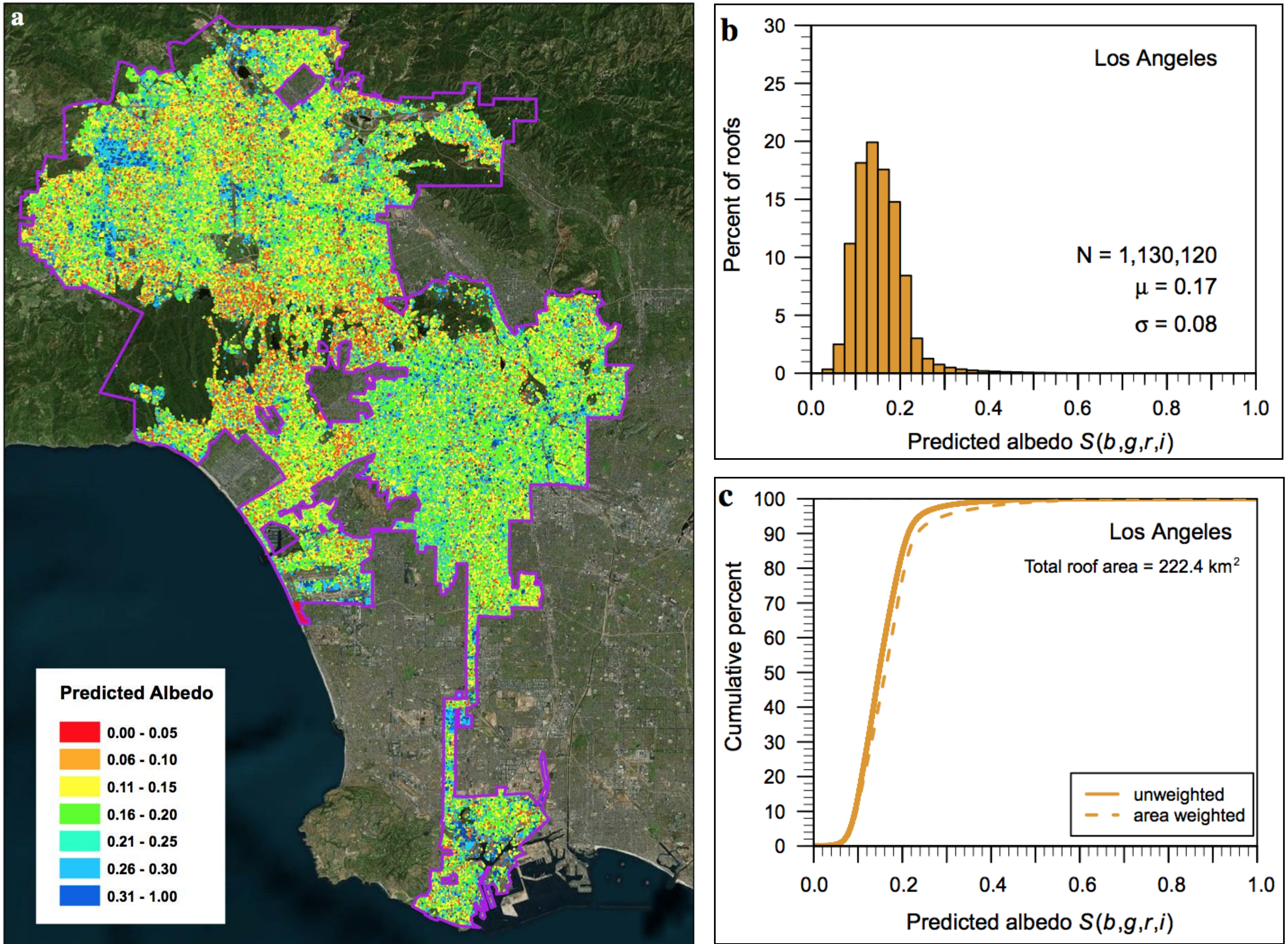
Results

Mean albedo for each rooftop

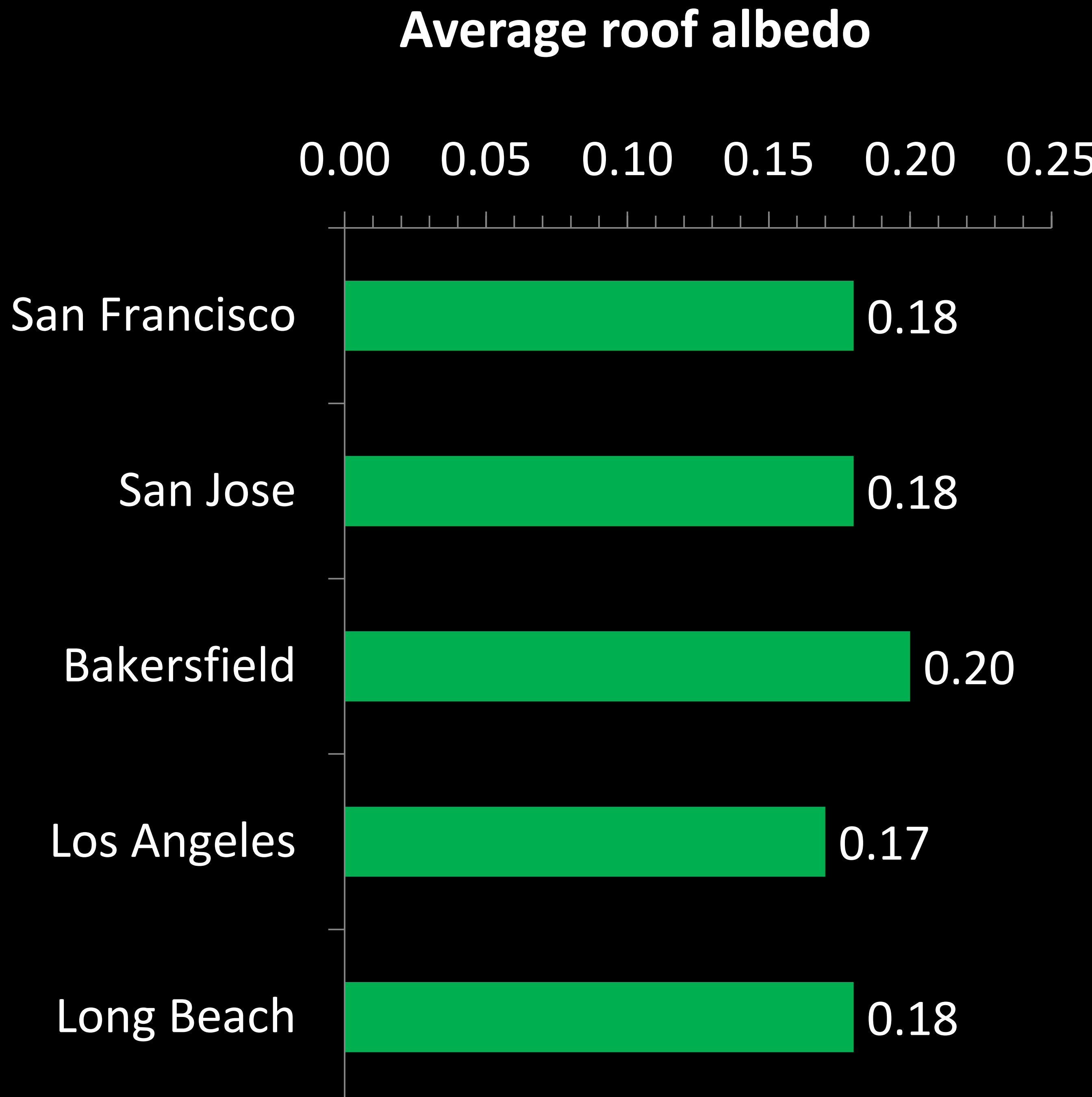


Source: Ban-Weiss et al. (2015b)

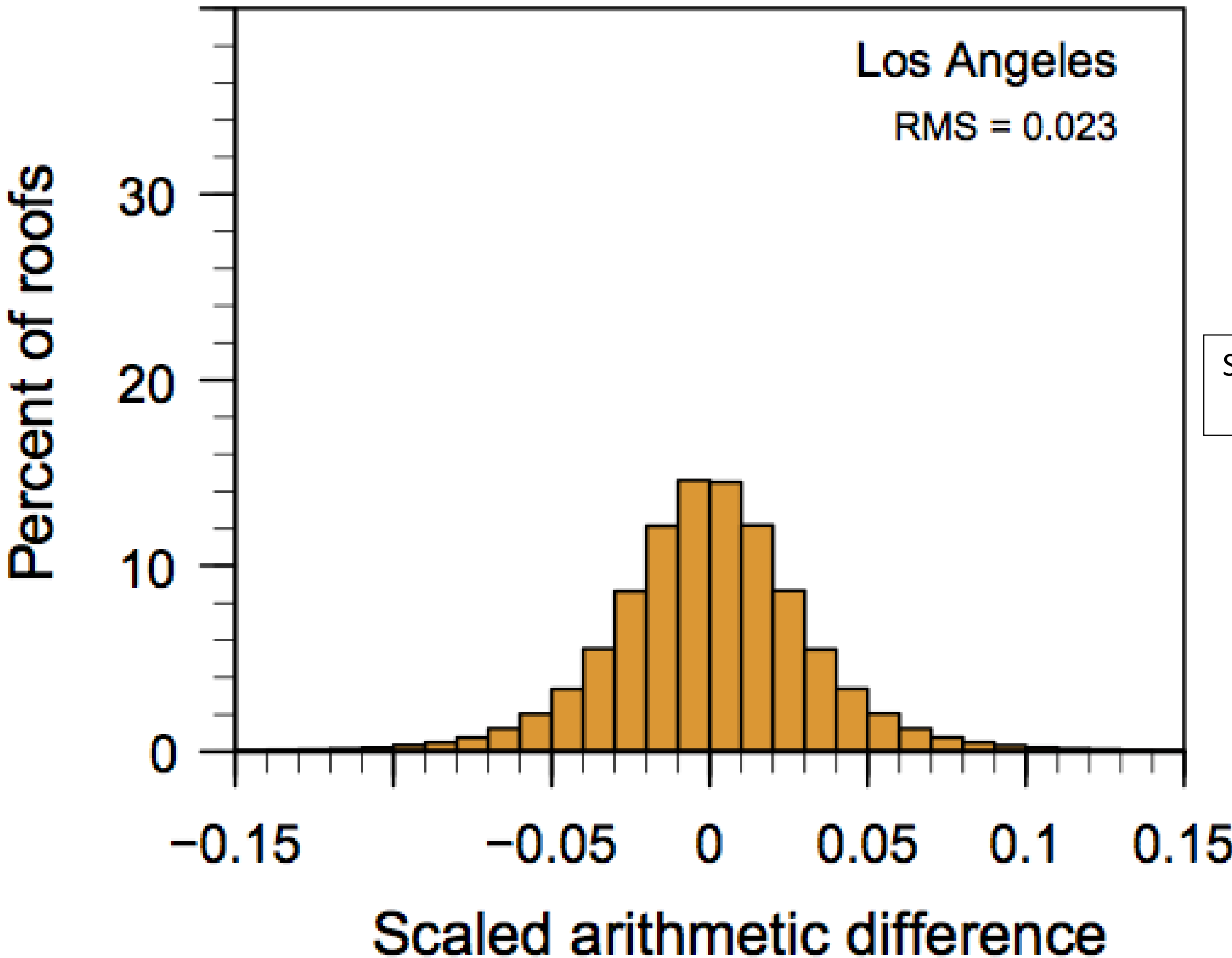
In Los Angeles most roofs have low albedo



Source: Ban-Weiss et al. (2015b)


Average roof albedo
0.00
0.05
0.10
0.15
0.20
0.25
San Francisco
0.18
San Jose
0.18
Bakersfield
0.20
Los Angeles
0.17
Long Beach
0.18

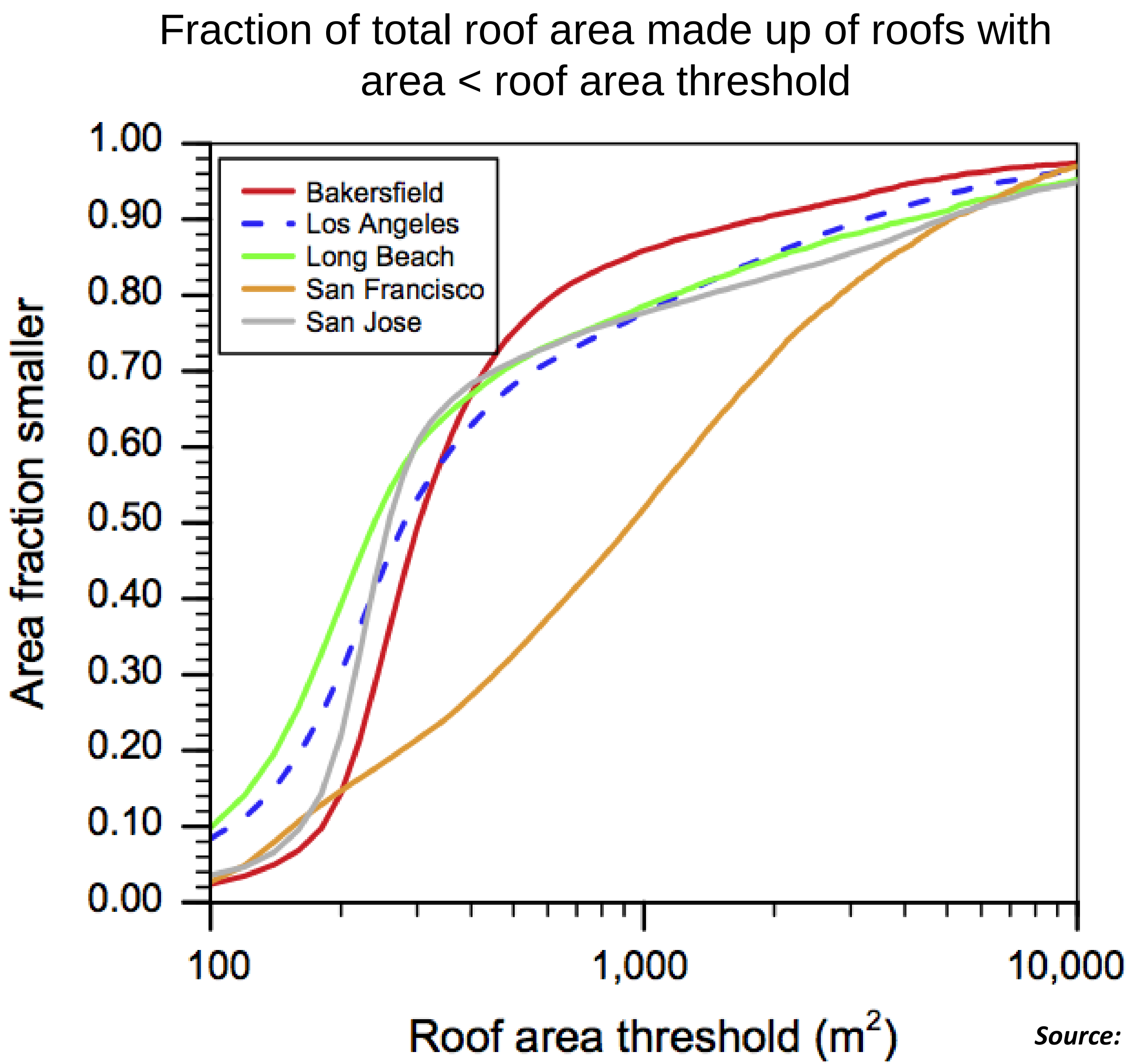
Assessing precision of our approach using multiple fly-overs: high precision!



Scaled arithmetic difference = (Refl1 – Refl2)/$\sqrt{(2)}$

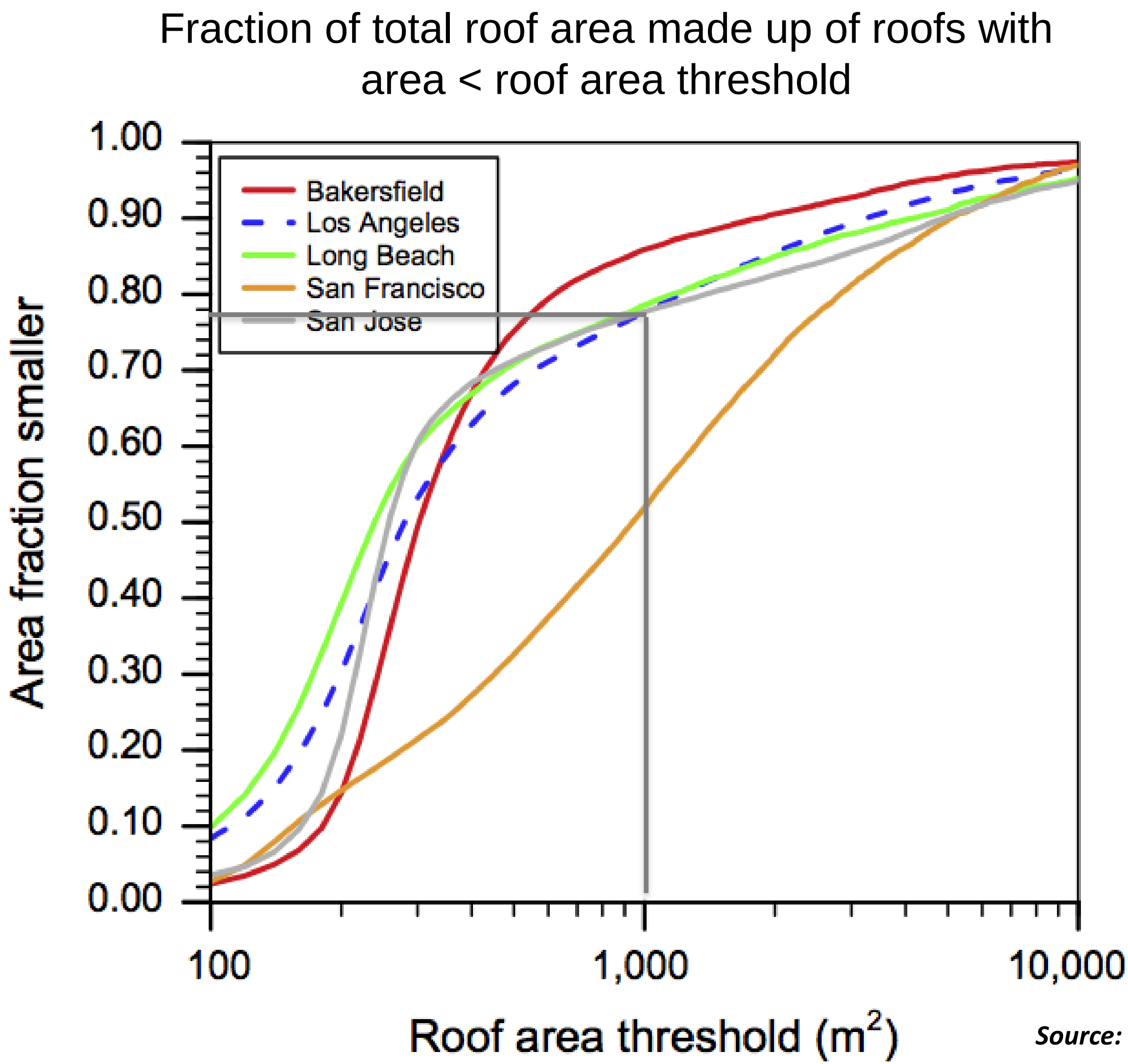
Source: Ban-Weiss et al. (2015b)

Most city-wide roof area is "small" roofs



Source: Ban-Weiss et al. (2015b)

Most city-wide roof area is "small" roofs

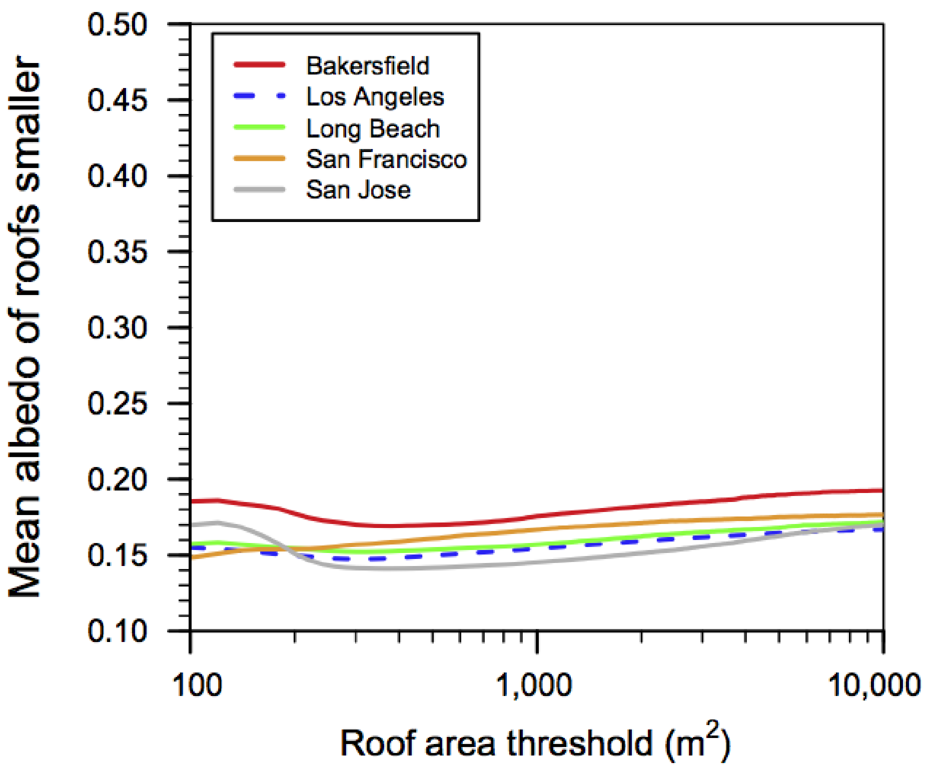


Source: Ban-Weiss et al. (2015b)

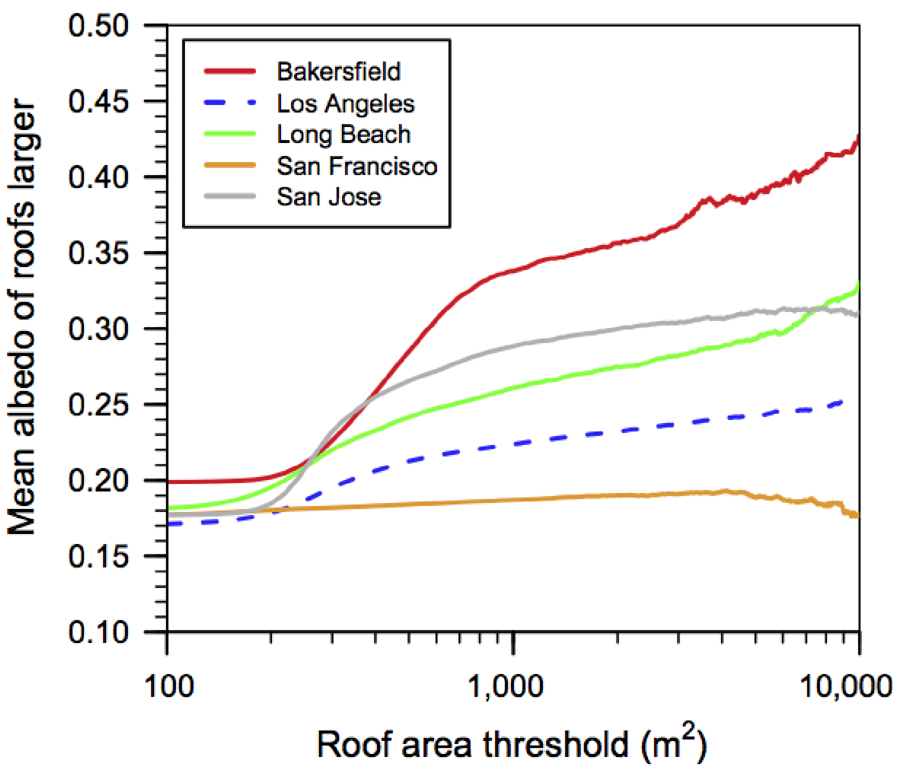
Small roofs have low albedo while larger roofs have higher albedo

Mean albedo of roofs with:

area < roof area threshold



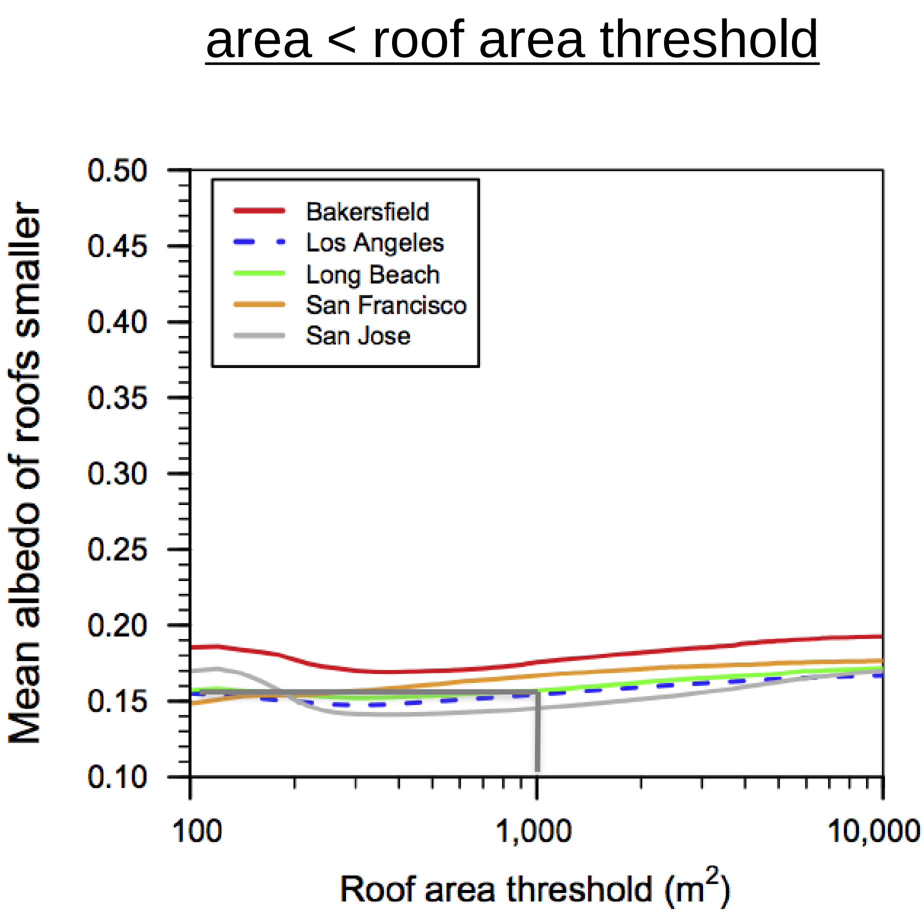
area > roof area threshold

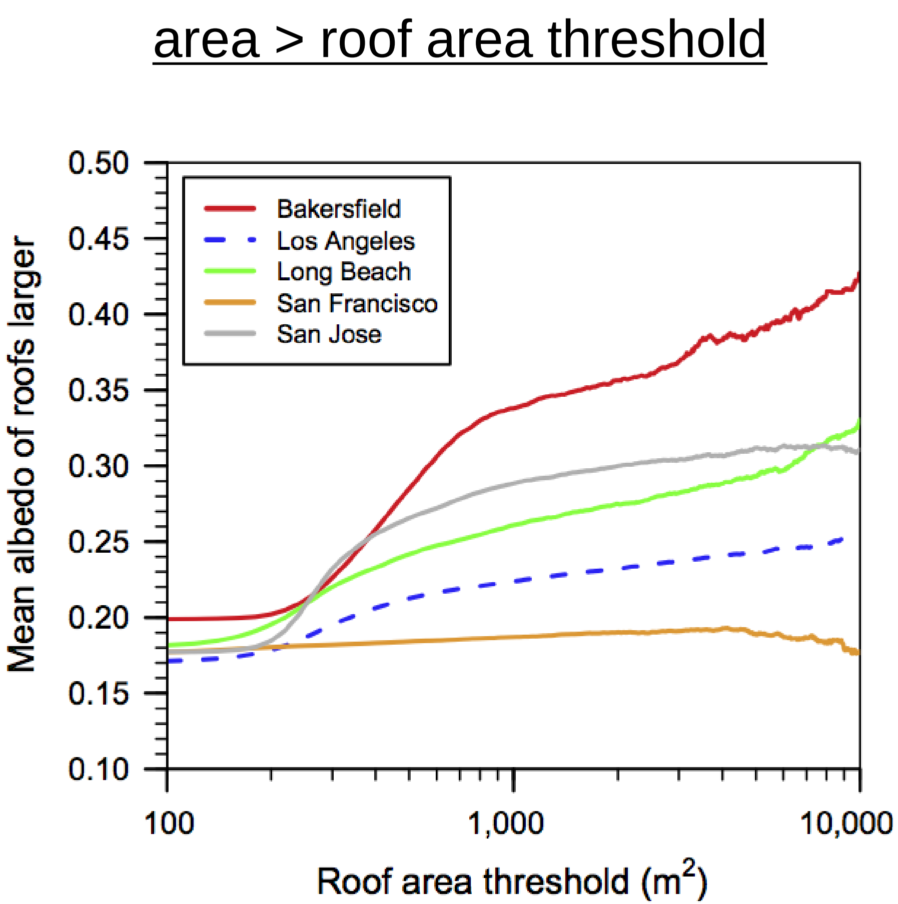


Source: Ban-Weiss et al. (2015b)

Small roofs have low albedo while larger roofs have higher albedo

Mean albedo of roofs with:



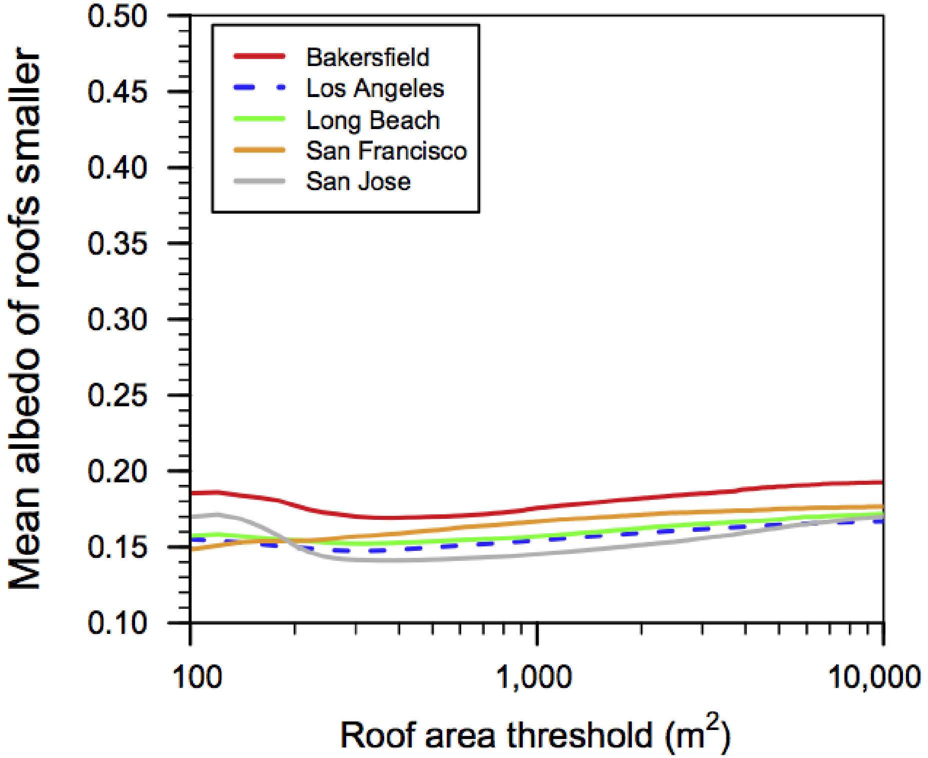


Source: Ban-Weiss et al. (2015b)

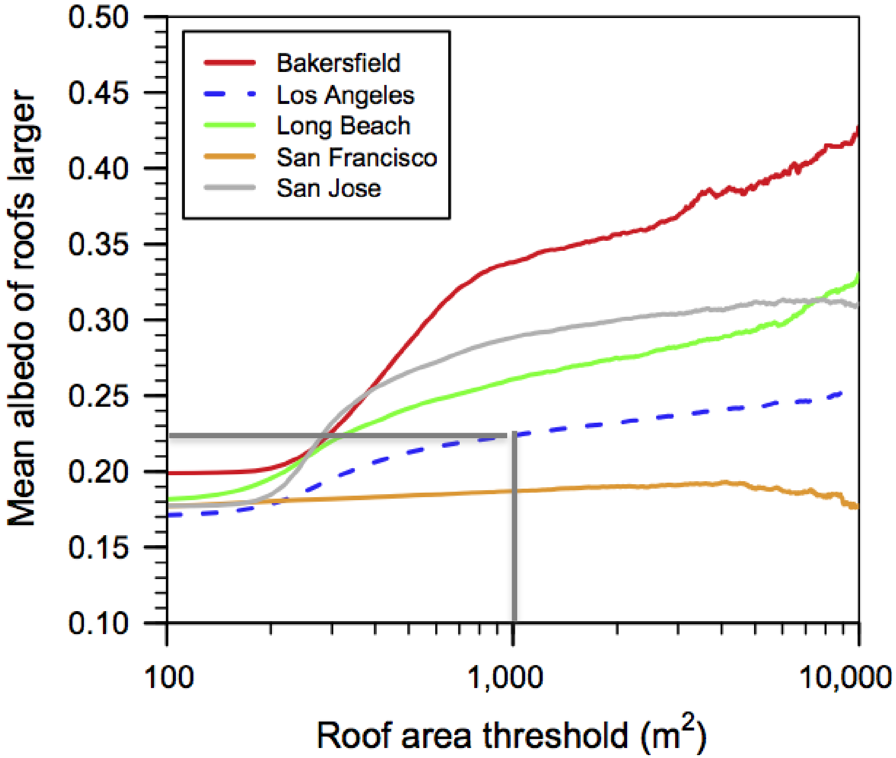
Small roofs have low albedo while larger roofs have higher albedo

Mean albedo of roofs with:

<u>area < roof area threshold</u>

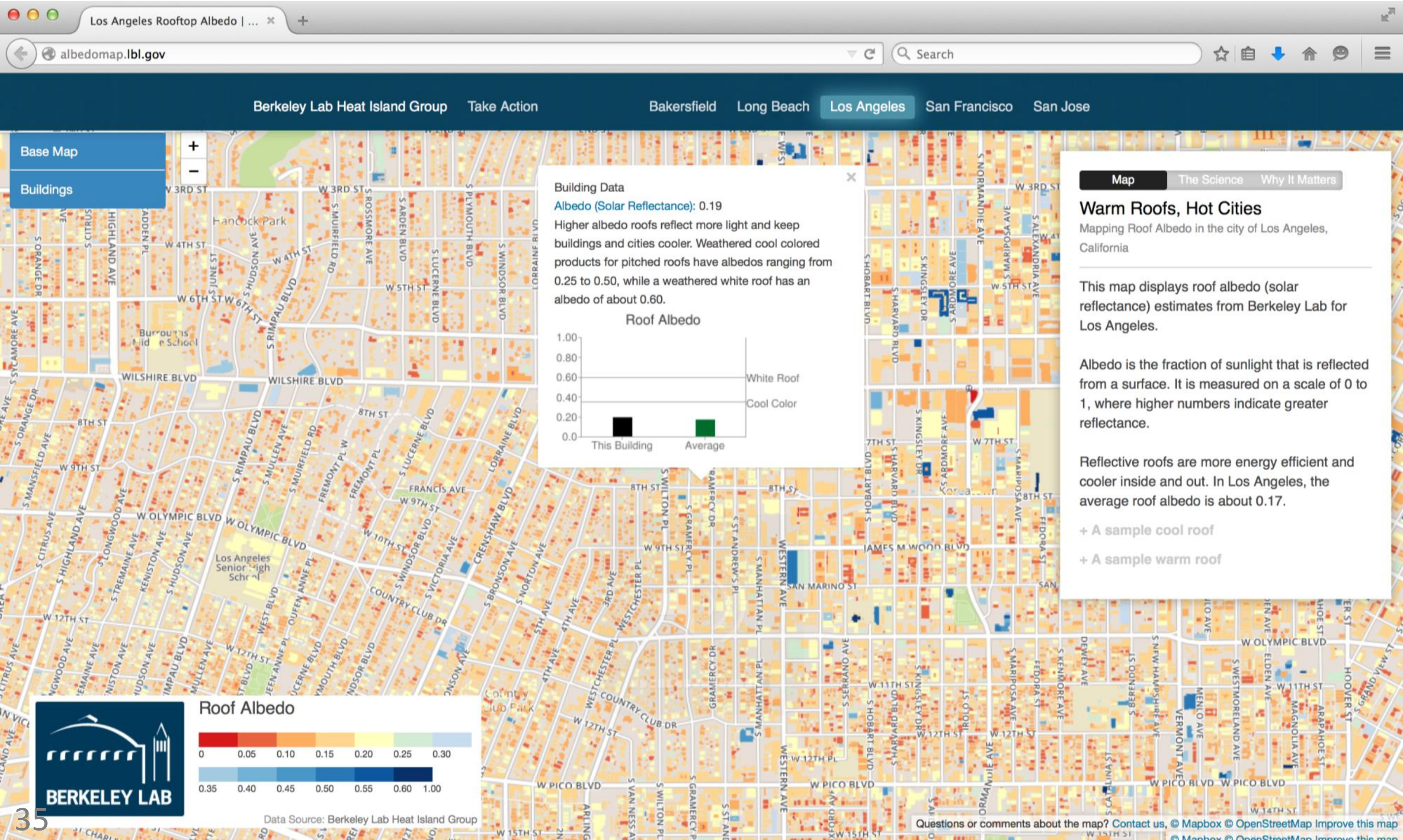


<u>area > roof area threshold</u>



Source: Ban-Weiss et al. (2015b)

albedomap.lbl.gov shows roof albedos for five California cities



Policy relevant conclusions

- Many commercial and residential buildings in California have roofs that could be made cooler (more reflective) to save energy
- Buildings with small roofs (primarily homes) constitute a large fraction of city roof area and have low albedos

Policy relevant conclusions

Therefore, efforts to increase urban-scale albedo for heat island mitigation and climate change adaptation should include cool roof requirements for residential buildings where appropriate (while maintaining desired aesthetics)

Latest policy developments for cool roofs

Los Angeles becomes the first major city to require cool roofs on *residential* buildings

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L.A. Passes "Cool Roof" Ordinance

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By Catherine A. Cardno, Ph.D.

In a bid to combat its urban "heat island effect," the city of Los Angeles has passed an ordinance that requires all new or renovated residential structures to install solar reflective roofing.

January 21, 2014—Last month, the Los Angeles City Council added a new ordinance to the city's 2014 municipal building code. Now all new and renovated residential structures—from small, single-family units to multistory apartment towers—will be required to install so-called "cool roofs," which reflect solar rays rather than absorbing the sun's heat and contributing to the city's warming.

"L.A. suffers from a strong urban heat island effect of 6°F or more compared to surrounding less developed areas," says Craig Tranby, an environmental supervisor in efficiency solutions at the Los Angeles Department of Water and Power, who wrote in response to written questions posed by *Civil Engineering* online.

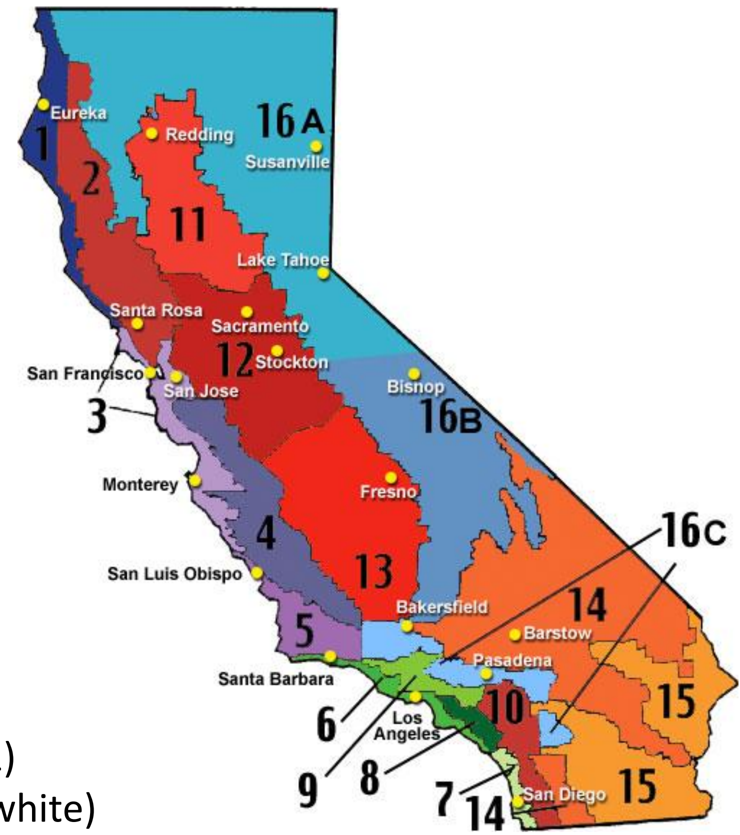
Under a new ordinance, all new and renovated residential structures, including multifamily structures, will be required to have roofs that reflect solar rays rather than absorbing the sun's heat. Wikimedia commons/Thomas Pintaric

In Los Angeles, the heat island effect has "resulted in a number of significant negative impacts on the environment, which the cool roofs will help address," Tranby said. At the community level, these negative impacts include decreasing roof and materials life, increasing overall and peak energy consumption as consumers cool buildings with air conditioning, and increasing heat-related illness among those who cannot afford to cool their structures. More broadly, the heat island effect also increases greenhouse gas and smog formation in the atmosphere, and decreases climate resiliency within the city, according to Tranby.

2013 Title 24 prescribes cool roofs for all nonres buildings, and some res buildings

	Min aged SR	Min aged TE	Min aged SRI
Nonres or high-rise res, low slope, all CZ	0.63	0.75	75
Nonres or high-rise res, high slope, all CZ	0.20	0.75	16
Res, low slope, CZs 13 & 15	0.63	0.75	75
Res, high slope, CZ 10 - 15	0.20	0.75	16

climate zone (CZ)



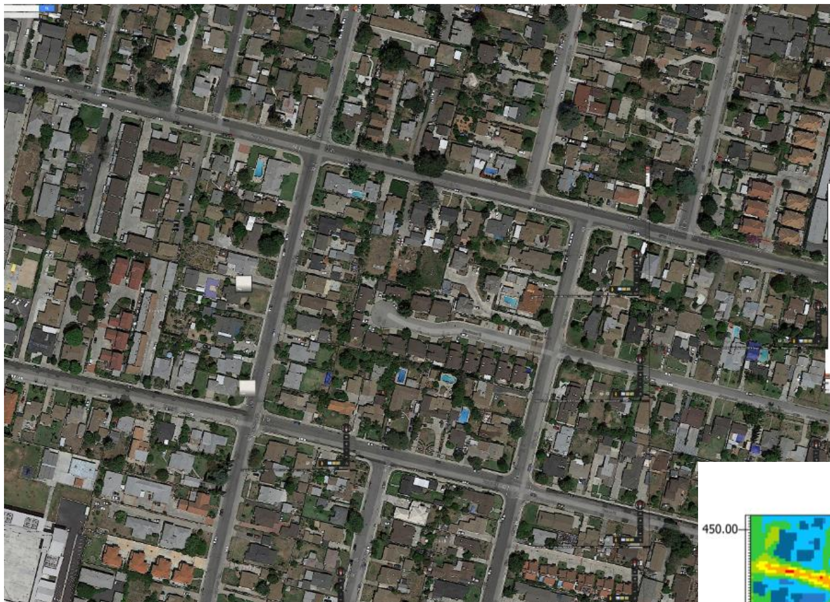
SR = solar reflectance (fraction of incident sunlight reflected, 0 - 1)
TE = thermal emittance (efficiency emitting thermal radiation, 0 - 1)
SRI = solar reflectance index (0 = reference black, 100 = reference white)

Current and future work

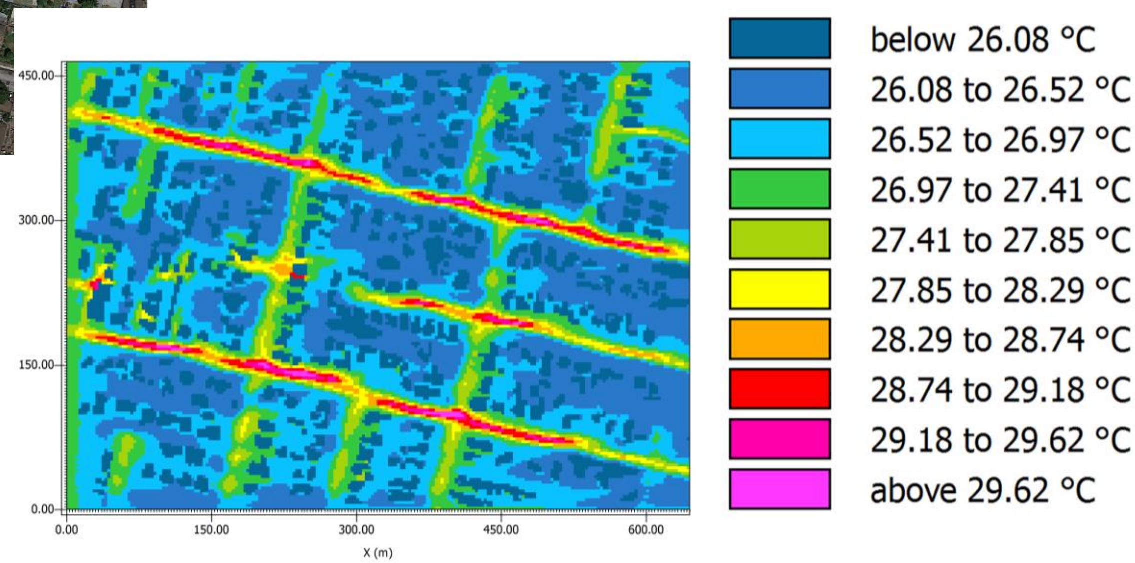
Life Cycle Assessment and Environmental Co-benefits of Cool Pavements

Project just wrapping up

Determining optimal urban heat mitigation strategies for vulnerable populations in a changing climate



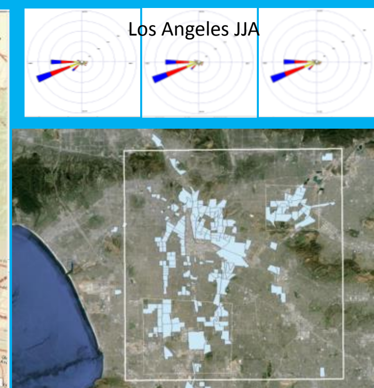
Surface air temperature



USC University of Southern California

Portland State University

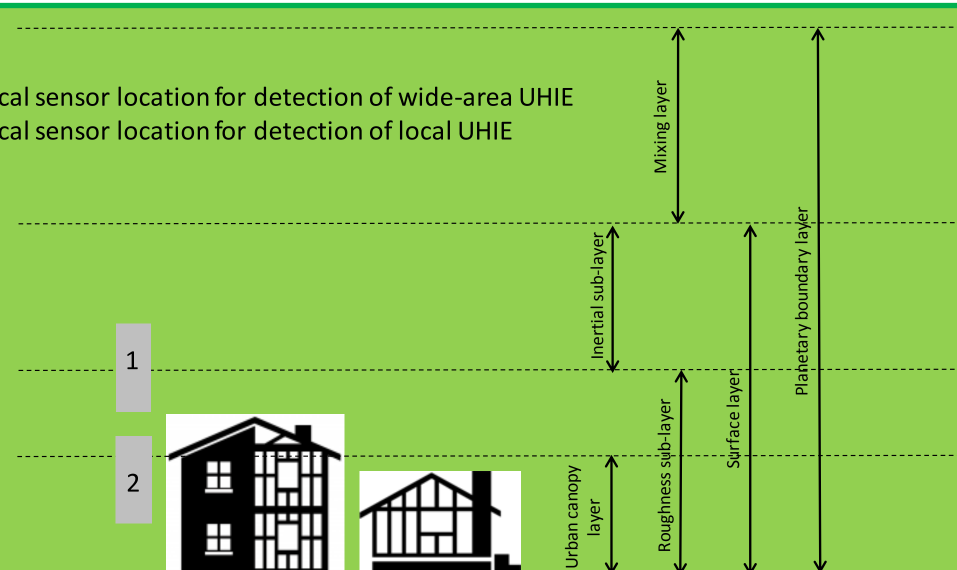
Upcoming LBNL-USC-Altostratus study will measure UHI in Los Angeles Basin



First guess of monitoring region (red oval). At bottom-right, the top 5 percent areas (census tracts) in CalEnviroScreen are highlighted. Top-right figure shows prevailing wind direction for June, July, and August in Los Angeles based on 30 years of data.

Conceptual framework for weather station siting. Shaded boxes represent possible heights of sensors for detection of (1) wide-area urban heat island effect (UHIE) (about 10 meters above ground level) and (2) local UHIE (about 2 meters above ground level). *Diagram not to scale.*

1: Vertical sensor location for detection of wide-area UHIE
2: Vertical sensor location for detection of local UHIE



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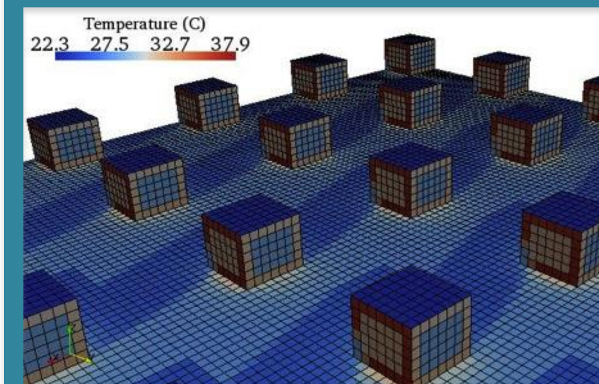
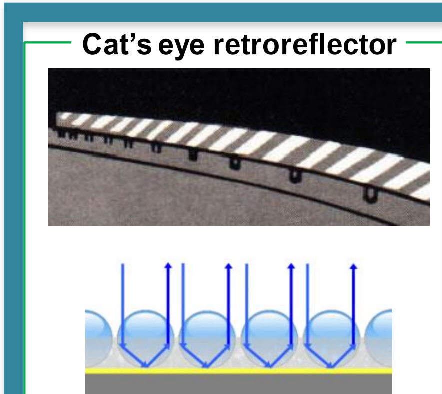
Solar-reflective "cool" walls: benefits, technologies, and implementation

Evaluate savings



Evaluate co-benefits

Assess technology

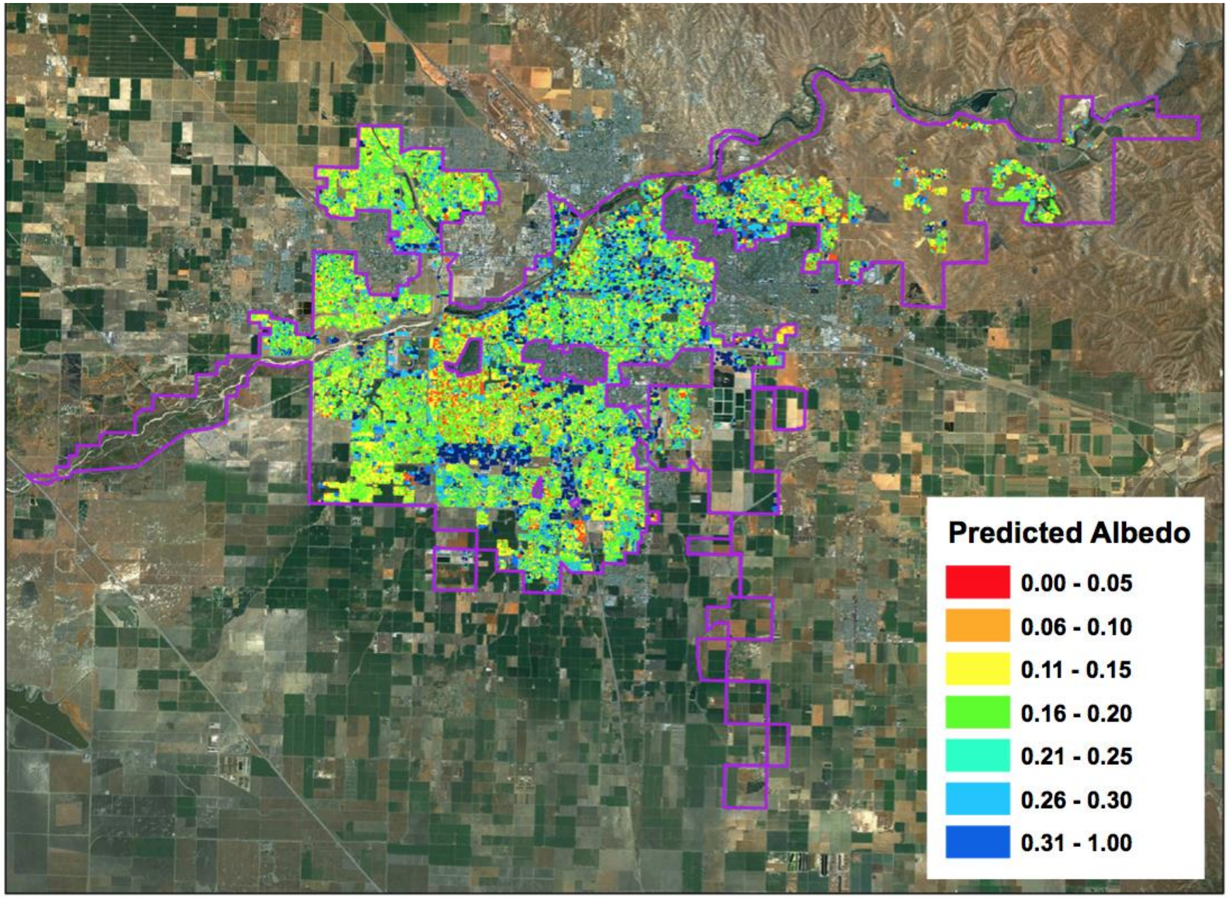


Develop technology

ENERGY STAR

Develop infrastructure

Thank you!



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Supplementary slides

City-wide mean albedos (and other stats)

City	Total roofs analyzed	Roofs with duplicate albedos	Total roof area (km^2)	Fraction of city covered by roofs	Mean albedo (standard deviation) [a]
Los Angeles	1,130,120 [b]	430,332	222.4	18	0.17 ± 0.08
Long Beach	136,582 [b]	37,344	26.9	20	0.18 ± 0.09
Bakersfield	109,237 [b]	53,541	30.5	10	0.20 ± 0.11
San Francisco	82,941 [b]	72,045	31.8	25	0.18 ± 0.08
San Jose	297,914 [b]	124,834	64.2	14	0.18 ± 0.12
Sacramento	1009 [c]	80	N/A	N/A	0.24 ± 0.11
San Diego	1003 [c]	548	N/A	N/A	0.29 ± 0.15

[a] Area weighted mean ± area weighted standard deviation

Statistics for roofs with area > 5,000 m²

Provides an estimate for the fraction of commercial buildings that obtained high albedo roofs due to Title-24 (as of 2009)

City	Percent of total roofs	Percent of total roof area	Percent with albedo >0.4
Los Angeles	0.1	7	8
Long Beach	0.2	9	14
Bakersfield	0.1	4	40
San Francisco	0.5	10	3
San Jose	0.2	10	22

Source: Ban-Weiss et al. (2015b)

Estimated error (accuracy) at 90% confidence interval

Albedo	Error											
	Los Angeles/Long Beach		Sacramento		San Jose		San Francisco		San Diego		Bakersfield	
	ε^U	ε^L	ε^U	ε^L	ε^U	ε^L	ε^U	ε^L	ε^U	ε^L	ε^U	ε^L
0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
0.2	0.01	0.01	0.02	0.02	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
0.3	0.01	0.02	0.03	0.03	0.00	0.00	0.02	0.02	0.00	0.00	0.01	0.01
0.4	0.02	0.02	0.04	0.05	0.01	0.01	0.03	0.03	0.01	0.01	0.02	0.02
0.5	0.03	0.03	0.06	0.07	0.02	0.02	0.04	0.04	0.02	0.02	0.03	0.03
0.6	0.04	0.05	0.07	0.08	0.02	0.03	0.05	0.05	0.03	0.03	0.04	0.04
0.7	0.05	0.06	0.09	0.10	0.03	0.04	0.06	0.07	0.04	0.04	0.05	0.05
0.8	0.06	0.07	0.10	0.12	0.04	0.05	0.07	0.08	0.05	0.05	0.06	0.06
0.9	0.08	0.08	0.12	0.14	0.06	0.06	0.09	0.10	0.06	0.07	0.07	0.08

Source: Ban-Weiss et al. (2015b)